Magnetic fields and dust in the massive filament G11.11-0.12 observed by SOFIA/HAWC+

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Collaboration: Vietnam Astrophysics Research Network (VARNet)

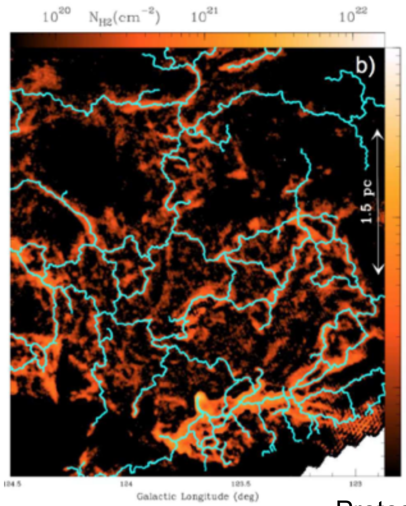
VARNet!

RVN@30, ICISE, 2023

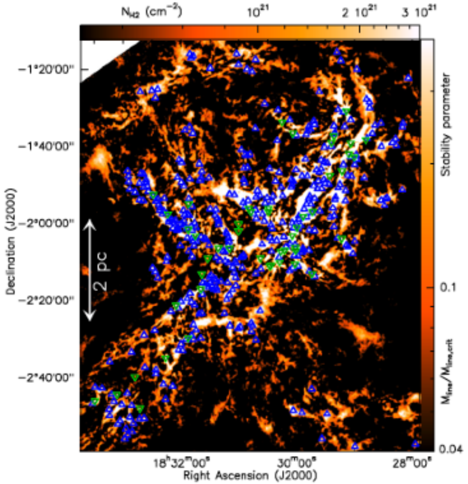
Contents

Role of filament

Filaments are ubiquitous. Prestellar cores protostars and are observed to be formed along filaments.
=> Filament is an important step in star formation.



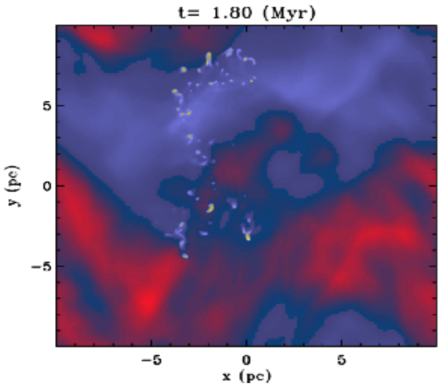
Konyves+2015



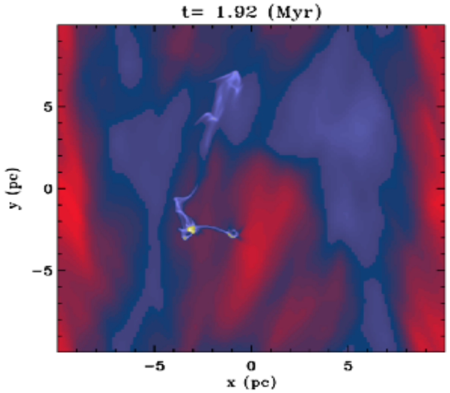
Protostars (green) candidate prestellar cores (blue)

Role of B-fields in filament

B-fields play an important role in star formation.
B-fields make matter flows more coherent and allows filaments to survive longer.



without B-fields



with B-fields

Hennebelle 2013

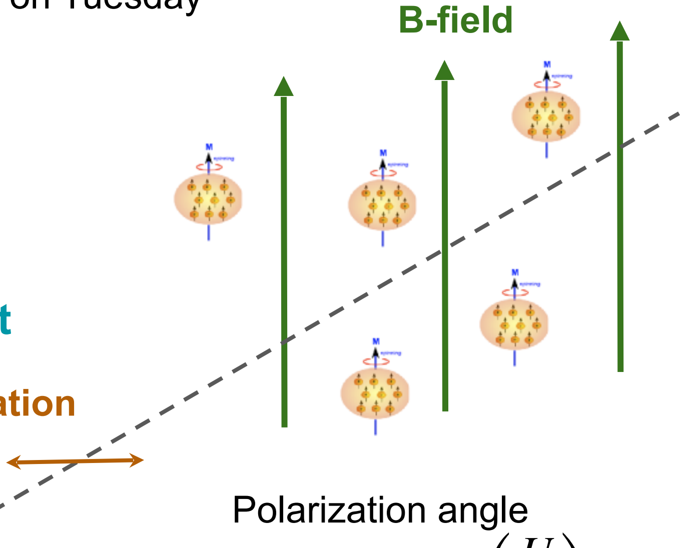
Dust polarization

Le Ngoc Tram's Talk on Tuesday

FIR/Sub-millimeter
Dust thermal emission

Grain Alignment

Polarization



Polarization angle

$$\theta = 0.5 \tan^{-1}\left(\frac{U}{Q}\right)$$

Polarization fraction

$$P = \frac{\sqrt{Q^2 + U^2}}{I}$$

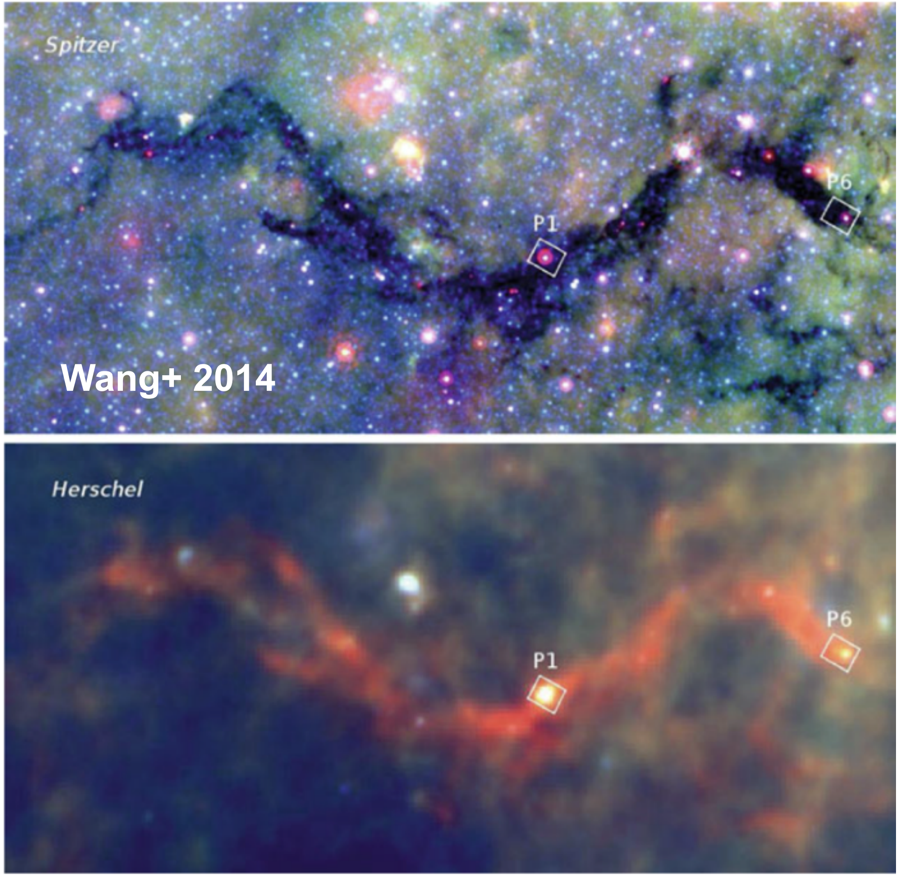
From dust polarization observation, we can study:

- **Magnetic fields** (morphology and strength)
- **Dust physics** (alignment and disruption, size, shape,…)

IFDC G11.11 -0.12 (Snake filament)

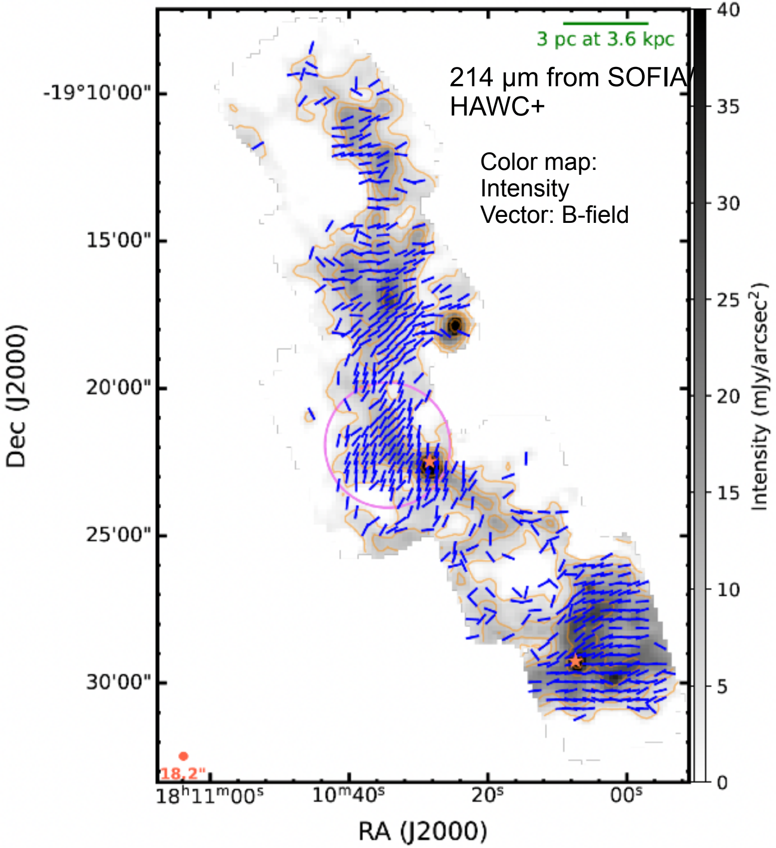
G11 is a filament in the galactic plane
Distance: 3.6 kpc from the Earth
Length: 30 pc
Mass: 10^4 $M_{\odot}$

In early phase of star formation with 18 cores along the filament and two high-mass protostar candidates (P1, P6) (Henning+2010)

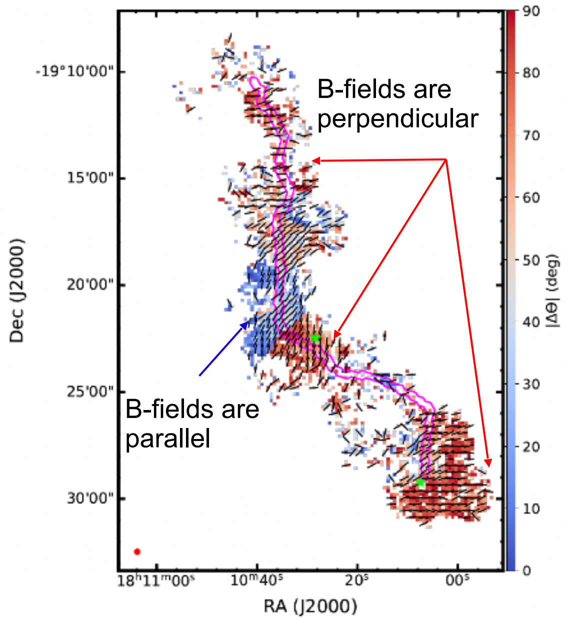


B-field morphology

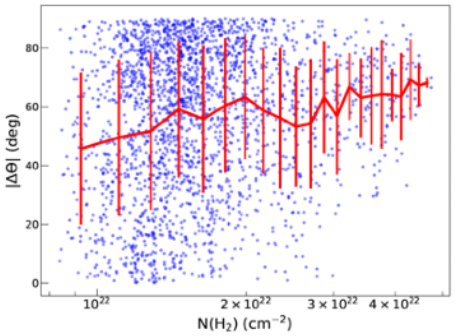
The first measurement of dust polarization towards the entire G11 filament



Angle difference between the B-fields and the bone



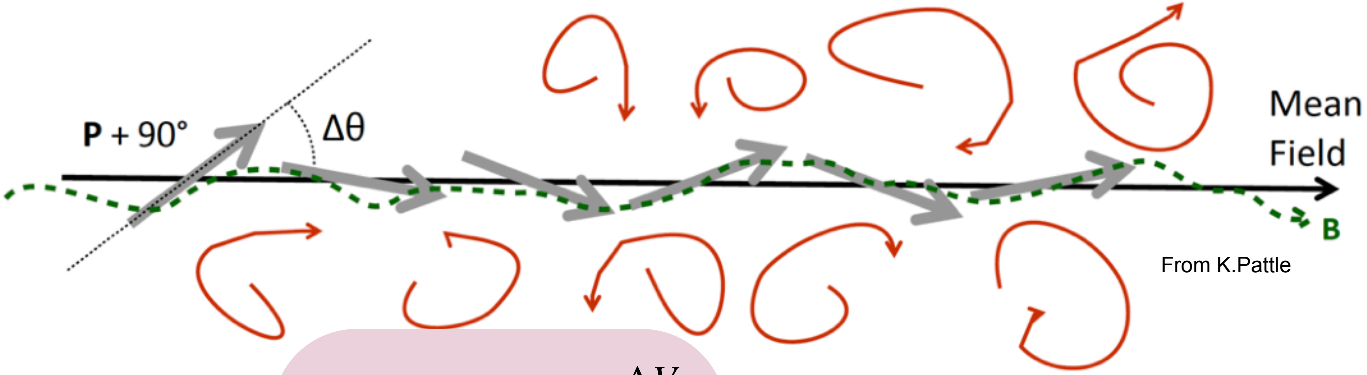
When B-fields run perpendicular to the filament, the filament is accreting materials following the B-fields



B-fields tend to change from parallel to perpendicular with the filament when density increases

Magnetic field strength: Davis, Chandrasekhar & Fermi method

It is based on the assumption that **gas turbulent motion is the driving of B-field distortion**



From K.Pattle

$$B_{\rm POS} = 9.3\sqrt{n({\rm H_2})}\frac{\Delta V}{\sigma_\theta}$$

(cf. Crutcher et al. 2004)

Relative importance

Mass-to-flux ratio: gravity vs. B-fields

$$\lambda = \frac{(M/\Phi)_{\rm observed}}{(M/\Phi)_{\rm critical}} = 7.6\times10^{-21}\frac{N({\rm H_2})}{B_{\rm POS}}$$

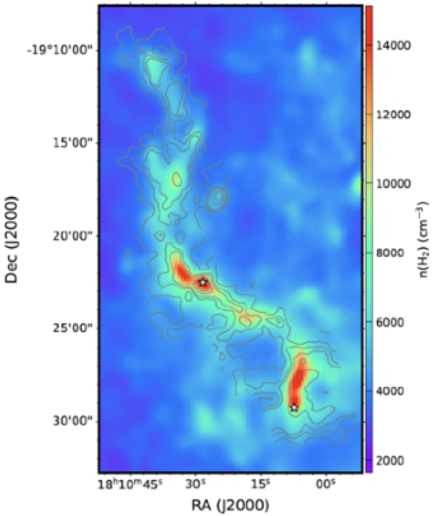
Alfvenic Mach number: turbulence vs. B-fields

$$\mathcal{M}_A = \frac{\sigma_{\rm V}}{\nu_A} = \frac{\sigma_\theta}{\mathcal{Q}}$$

Magnetic field strength: Davis, Chandrasekhar & Fermi method

$n(H_2)$ volume density

($N(H_2)$ Herschel)

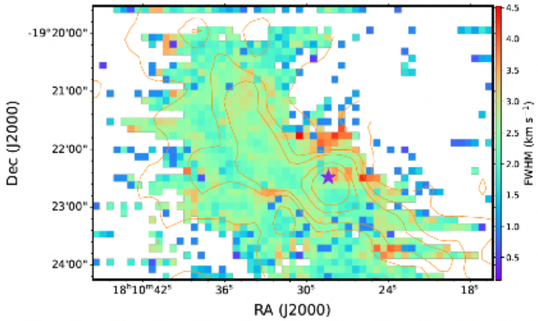


Assume: Depth = width ~ 0.9 pc (Zucker+18)

$n(H_2) = N(H_2)$/depth

ΔV velocity dispersion

($^{13}CO(3-2)$ HARP/JCMT)



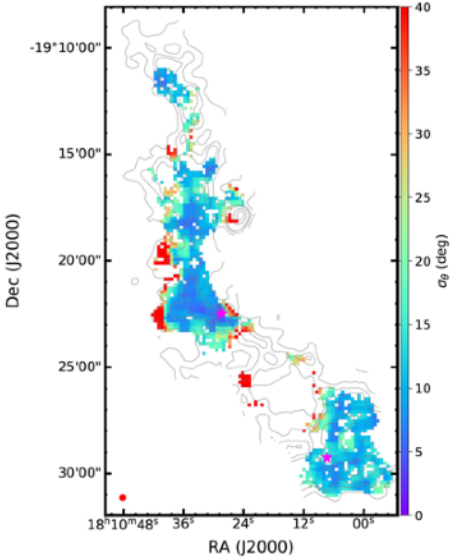
$$\Delta V = \Delta V^2_{\rm total} - \frac{kT}{m} 8 \ln 2$$

$\Delta V^2_{\rm total}$: FWHM of spectral line

$$B_{\rm POS} = 9.3\sqrt{n(\mathrm{H_2})}\frac{\Delta V}{\sigma_\theta}$$

(Crutcher 2004)

σ_θ polarisation angle dispersion



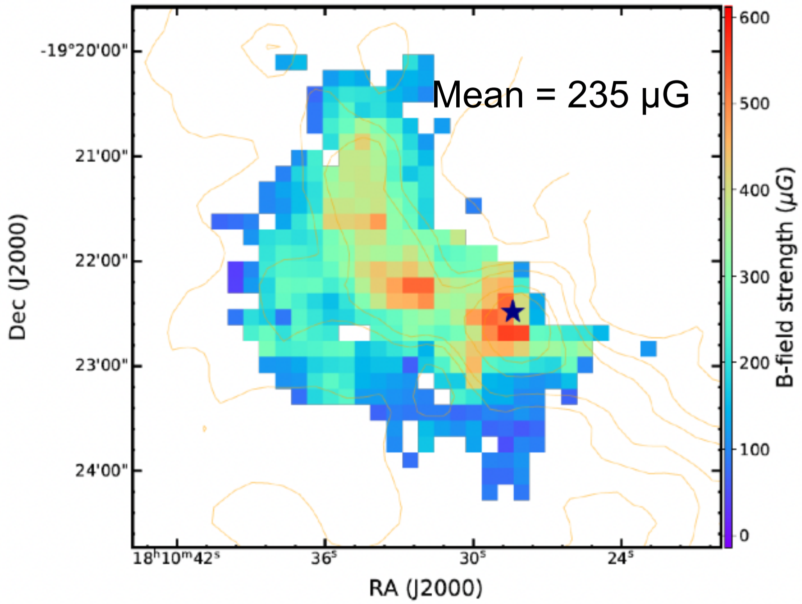
$$\sigma_\theta = \sqrt{\sum_{i=1}^{25} (\theta_i - \bar{\theta})^2/25}$$ (Hang et al. 2021)

$\bar{\theta}$ mean angle of 5x5 box

θ_i polarization angle of pixel i

B-field strength

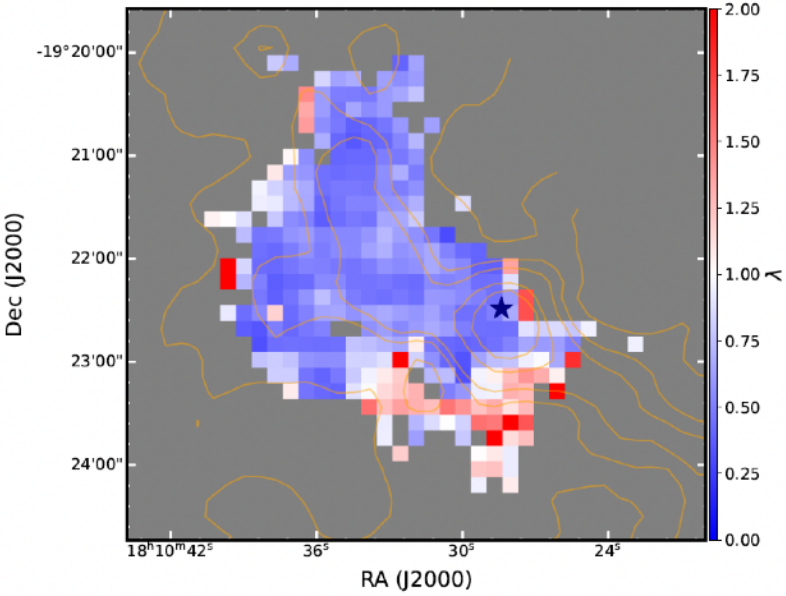
The strengths vary in the range of 100-600 μG and are strongest along the filament's bone.



Mass-to-flux ratio

The region is mostly **subcritical.**

B-fields are strong enough to resist gravitational collapse.

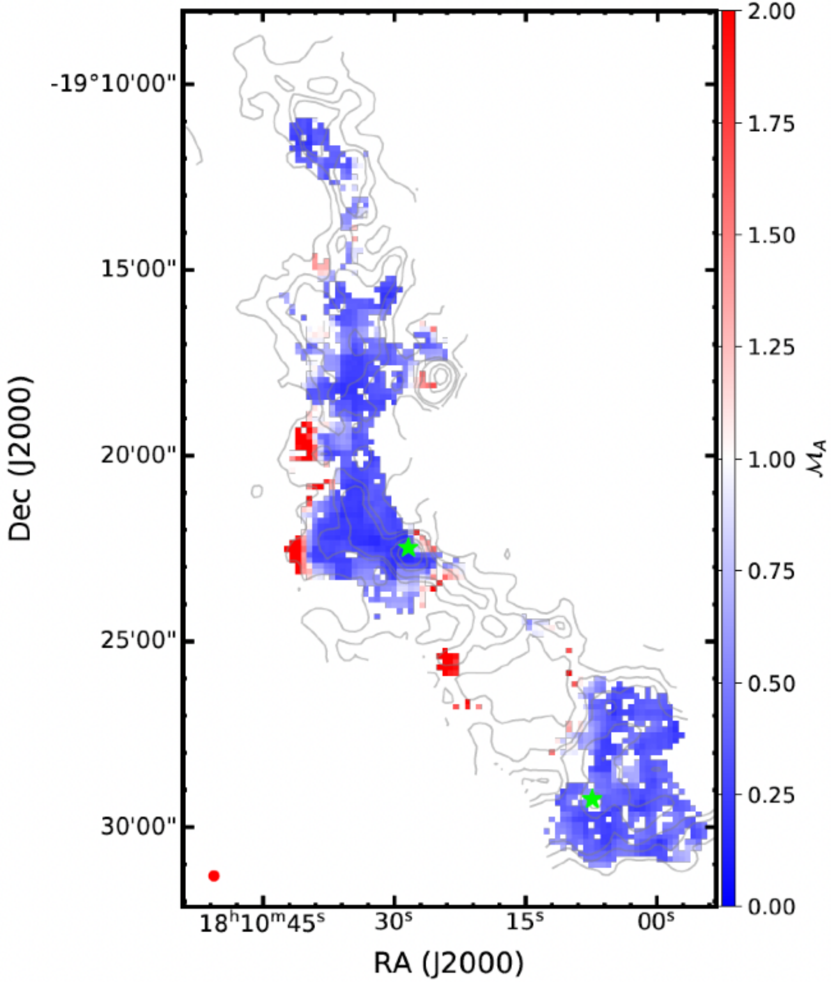


Alfvenic Mach number

The filament is sub-Alfvenic

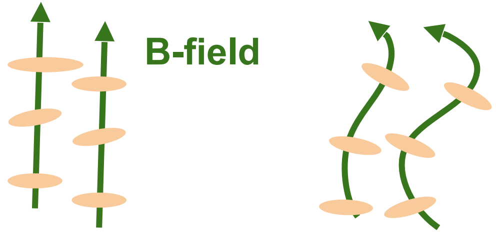
B-fields dominate over turbulence

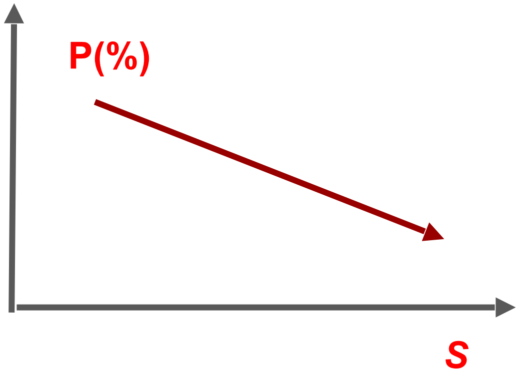
=> the magnetic fields are able to regulate the gas motion



Dust physics

B-field tangling

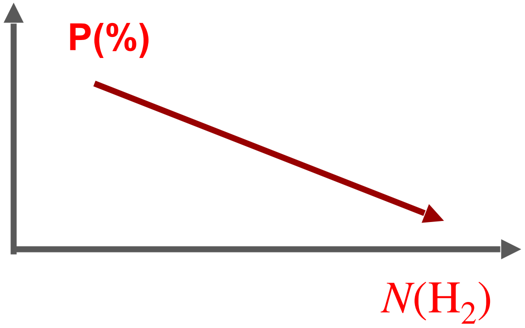




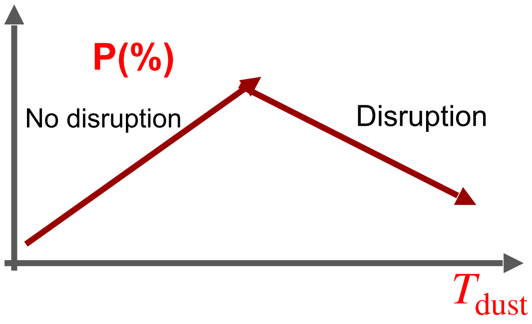
S is to quantify the B-field tangling
PxS shows the alignment efficiency

Environmental conditions

Gas density

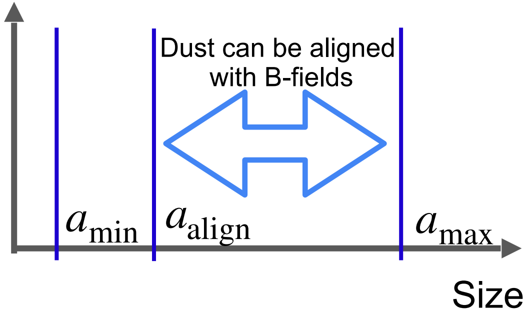


Radiation field ~Dust temperature

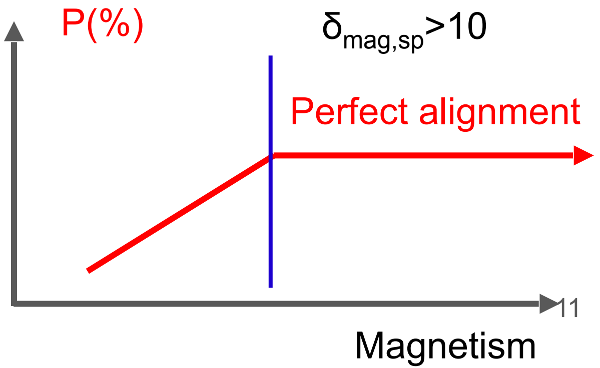


Dust properties

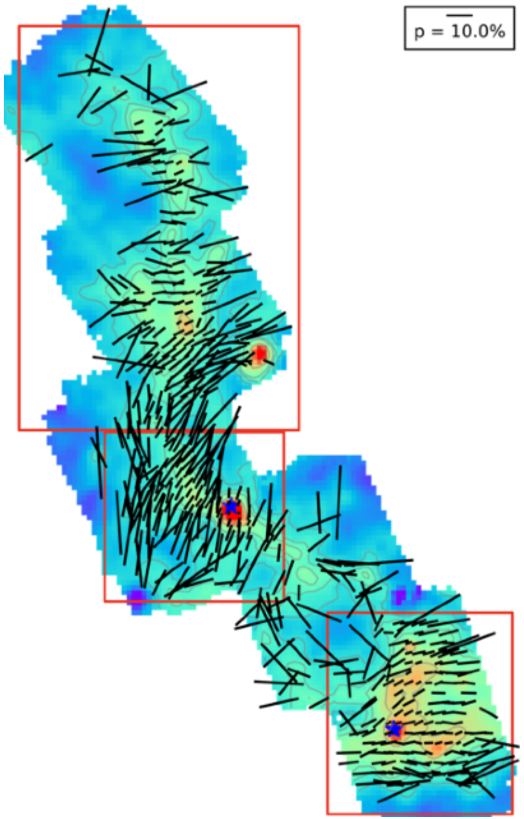
Grain size

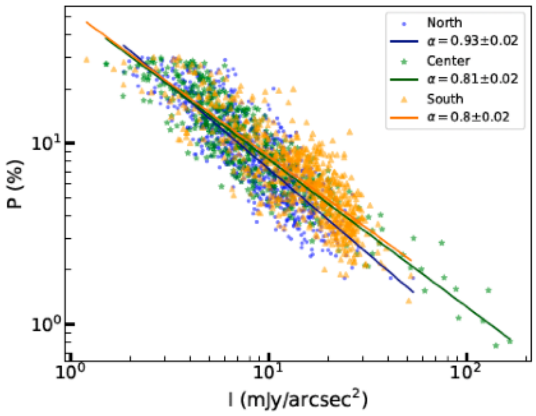


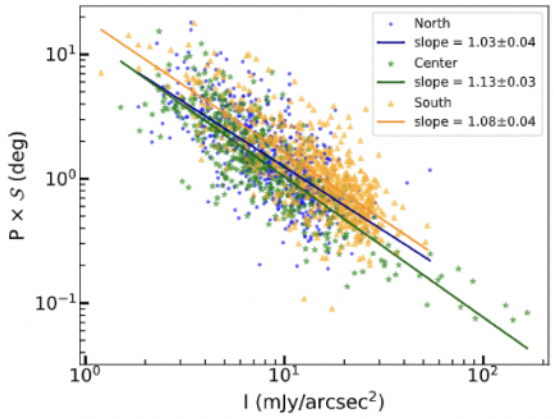
Iron clusters are blocked inside grain



Depolarization effect: B-field tangling







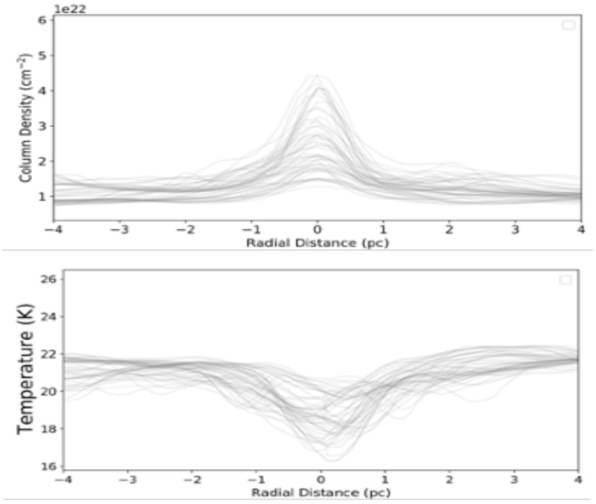
The depolarization hole in the filament bone

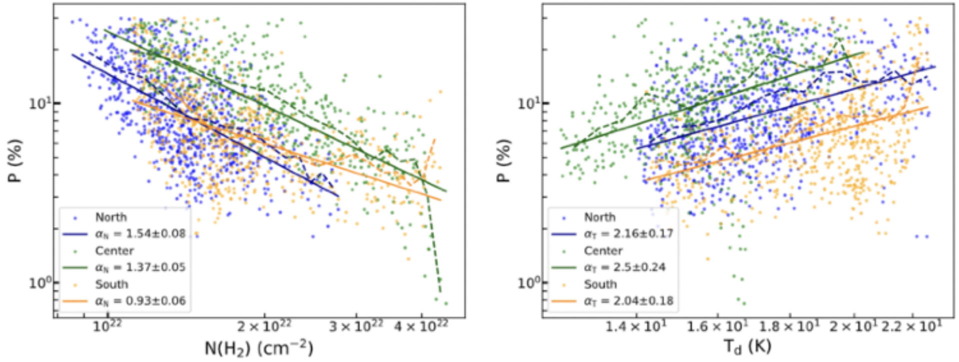
The alignment efficiency (*PxS)* decreases with increasing I

=>B-field tangling cannot be the reason of the depolarization effect

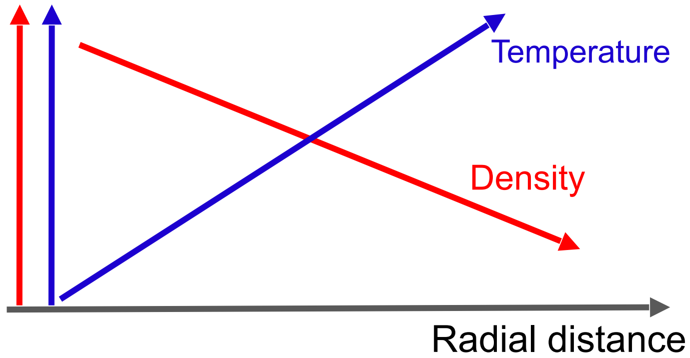
Depolarization effect: Implications for Grain Alignment Theory

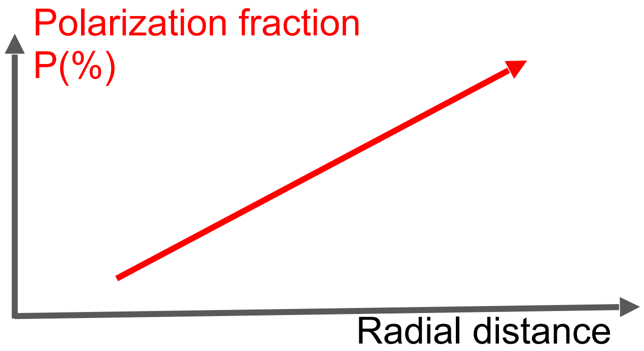
Filament profiles





The polarization decreases because of the decrease in grain alignment efficiency toward the high column density and low dust temperature



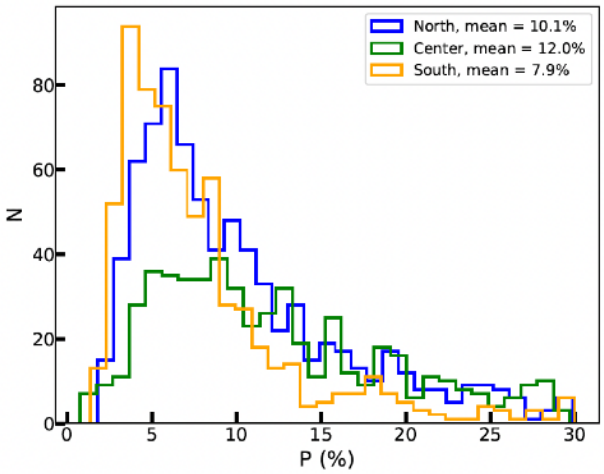


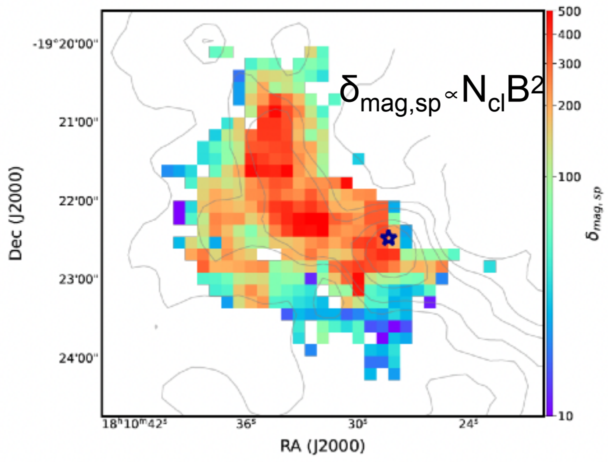
Enhanced Magnetic Relaxation on RAT Alignment (MRAT)

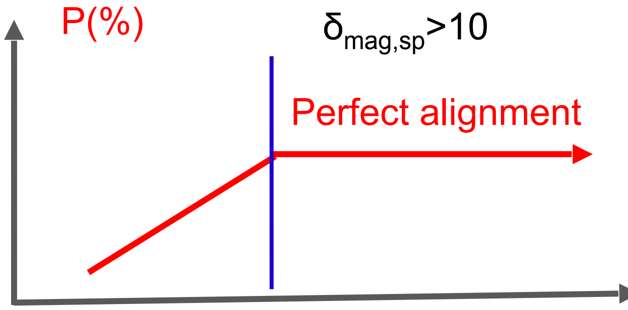
P(%) > 20%, can be achieved only if grains can be perfectly aligned

=> Combination of the MRAT and RATs.

=> Grains in G11 contain iron clusters







Grain growth

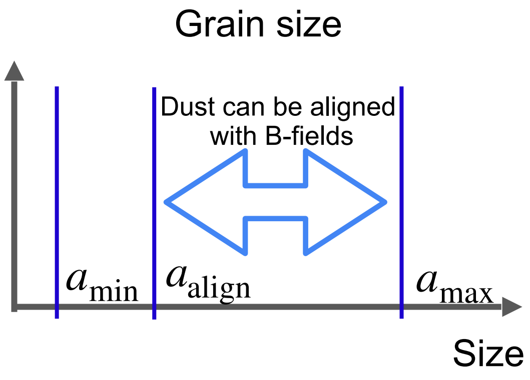
a_{align} : minimum size of aligned grains (Hoang et al. 2021).
Dust can be aligned in range of a_{align} to a_{max}

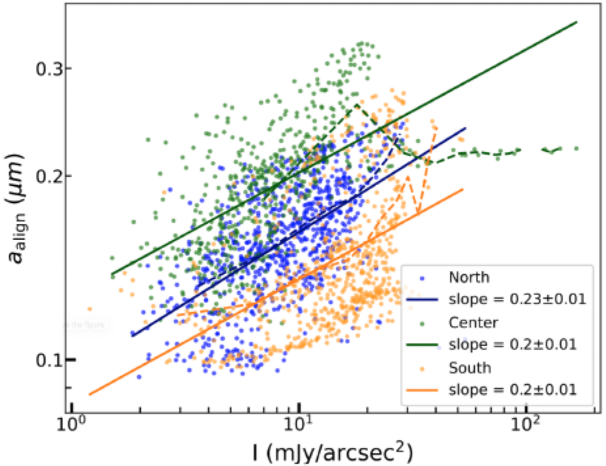
Slope of *I* vs *P* ~ 0.8-0.9 < 1

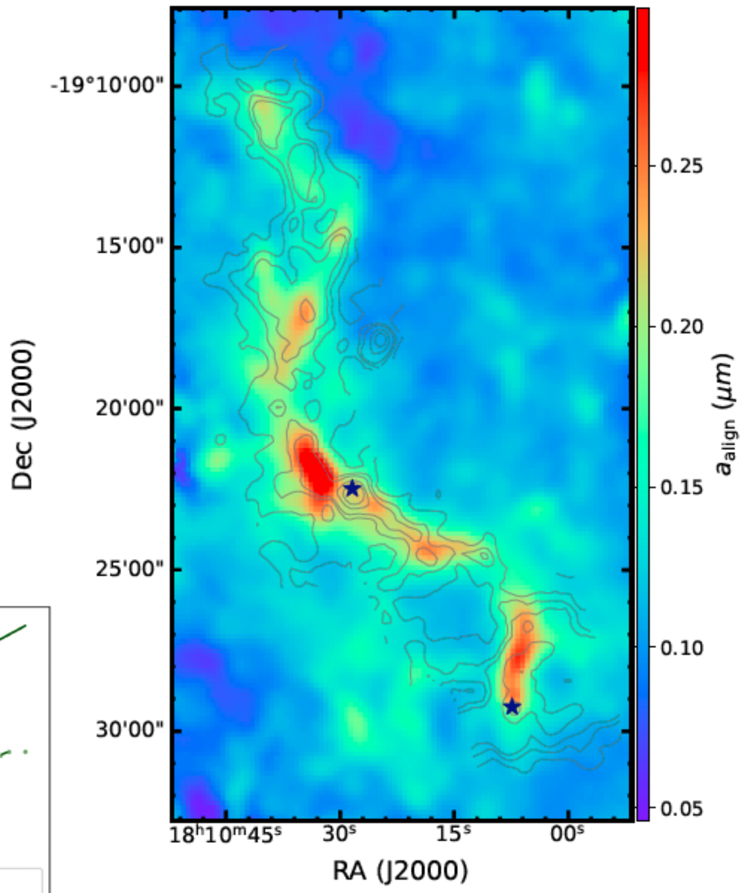
=> grain alignment is not completely lost

Inside filament: $a_{max} > a_{align}$ = 0.3 μm > a_{max} (ISM) =0.25 μm

=> Grain growth in the filament







Conclusion

G11 paper

Magnetic field

- B-field morphology is fully mapped along the Snake filament.
- The general B-fields tend to be perpendicular to the filament.
- Maps of B-field strength, mass-flux ratio, Alfvenic mach number of the densest region of G11. B-fields dominate over turbulence and are strong enough to resist gravitational collapse.

Dust physics

- The depolarization can be explained by the decrease in RAT alignment efficiency toward the denser and lower dust temperature regions.
- We find the evidence for grain growth and iron cluster in dust grains.

Thank you very much for your attention!